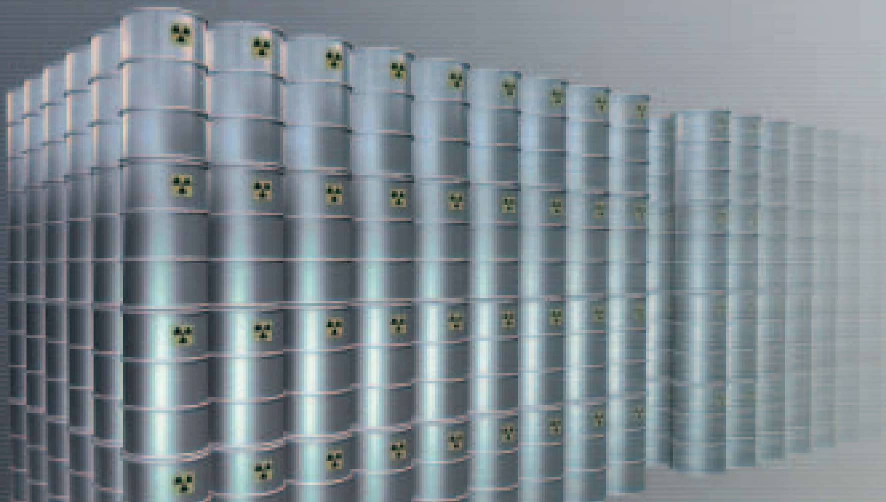
The Long Term Storage of Radioactive Waste: Safety and Sustainability

A Position Paper of International Experts



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THE LONG TERM STORAGE OF RADIOACTIVE WASTE: SAFETY AND SUSTAINABILITY

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FOREWORD

Storage is a necessary step in the overall management of radioactive waste. In recent years, mainly because of the unavailability of permanent disposal facilities, stores originally intended as temporary facilities have had their lifetimes extended and serious consideration has been given, in some countries, to the use of storage as a long term management option.

Attention was drawn to these developments at the International Conference on the Safety of Radioactive Waste Management, held in Córdoba, Spain, in March 2000. A conclusion of the conference was that perpetual storage of radioactive waste is not a sustainable practice and offers no solution for the future. Subsequently, an action programme based on the findings of the Córdoba conference was approved by the General Conference of the IAEA in September 2001. One of these actions was to “assess the safety implications of the extended storage of radioactive waste and of any future reconditioning that may be necessary”. The IAEA was requested to investigate the role of extended storage in a sustainable programme of radioactive waste management, and especially the implications for safety.

The present report has been produced in partial fulfilment of the request to the IAEA. The purpose of the report is to reflect the currently prevailing views among experts in the field. It is intended for use as a central and authoritative reference point for national discussions and policy papers. It is therefore potentially useful to national committees and bodies concerned with the management of radioactive waste. It may also be of value to concerned members of the public since it is written in language that should be comprehensible to the informed layperson. It was produced as a result of several meetings of experts in the first part of 2002. Since then, it has been reviewed by the WASSC Subgroup on Principles and Criteria for the Disposal of Radioactive Waste, at its meeting in September 2002, by a Technical Committee convened specifically to review the document at a meeting held in November 2002, and by the International Waste Safety Standards Committee (WASSC) in December 2002. Finally, the essential conclusions of the paper were presented to and discussed with participants to the International Conference on Issues and Trends in Radioactive Waste Management, held in Vienna in December 2002.

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1. INTRODUCTION

In 1995 the International Atomic Energy Agency (IAEA) published The Principles of Radioactive Waste Management, Safety Series No. 111-F [1]. This publication reflected a significant international consensus on principles important to the safety of radioactive waste management.[1]

One of the nine principles set forth in Ref. [1] is that "Radioactive waste shall be managed in such a way that will not impose undue burdens on future generations". This statement was based on the ethical consideration that the generation that receives the benefit from an activity should also commit to taking care of any liabilities from that activity, in this case, the radioactive waste that arises from nuclear energy production. It has been broadly interpreted to imply that the generation that generates radioactive waste should make all the arrangements needed for the disposal of the waste.

In most countries, nuclear power generation and other applications of radioactive materials started before plans for the disposal of the resulting radioactive waste were well developed. As waste arose, it was most frequently stored in various types of engineered containment on the surface and at sites to which access was controlled. Research and development work on waste disposal has shown that, in principle, all types of radioactive waste can be disposed of in a manner that provides protection for the health and safety of people and the environment. For high level and long lived radioactive waste, the consensus of the waste management experts internationally is that disposal in deep underground engineered facilities — geological disposal — is the best option that is currently available or likely to be available in the foreseeable future [2]. This option is under investigation in most countries with significant amounts of such waste, and two countries have now made formal Government decisions to go ahead with facilities for the disposal of high level waste. Difficulties have been encountered in several countries, however, in proceeding with the development and construction of disposal facilities for high level radioactive waste and as yet no such disposal facilities are in operation. Thus, the waste material continues to accumulate in storage facilities.

There are many reasons for these difficulties, some of which are discussed later in this paper. But as the amounts of radioactive waste in surface storage have increased, concern has grown over the sustainability of storage in the long term and the associated safety and security implications [3–8]. At the same time, some countries have chosen to study the feasibility and implications of long

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[1] The principles set forth in Ref. [1] were subsequently used to provide the technical basis for the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management which entered into force in June 2001.

term storage options. The issue was also discussed at length at the international conference on radioactive waste management held in 2000 in Córdoba, Spain [9]. Subsequently, as part of the follow-up Waste Safety Action Plan, the IAEA Secretariat was requested to investigate the role of long term storage in a sustainable programme of radioactive waste management, and especially the implications for safety compared to those provided by subsurface disposal [10].

This report is concerned particularly with the storage of three main types of waste: high level waste from the reprocessing of nuclear fuel; spent nuclear fuel that is regarded as waste; and long lived intermediate level radioactive waste. It does not address mining and milling waste, and other large volumes of waste from processes involving the use of naturally occurring radioactive materials.

2. TYPES OF FACILITIES

The characteristics of storage and disposal facilities may vary significantly. Some general characteristics can be described, however, which are relevant to the discussion later in this paper.

2.1. STORAGE FACILITIES

Up to the present, storage facilities for high level waste and spent fuel have typically been above ground or at very shallow depth. The waste is stored either dry or underwater. Most spent fuel, for example, is stored underwater for a period of at least three to five years after removal from the nuclear reactor, the water serving as radiation shielding and also as a means of maintaining the spent fuel elements at an acceptably low temperature. In some countries, the spent fuel is then transferred to storage in dry conditions. Spent fuel can also be reprocessed and the resulting highly radioactive liquors are solidified by vitrification. Most other solid radioactive waste is also stored in dry conditions.

Depending on its characteristics, the waste may undergo conditioning before being packaged inside a container. Some containers used for this purpose are designed to be extremely durable and resistant to corrosion or other forms of degradation for many years. The containers are then stored inside a suitable structure, often constructed from concrete, to provide radiation shielding and security. These structures, whether buildings in the conventional sense or other types of massive form, are usually located at a secure site inside a perimeter security fence.

In some instances, storage is in the ground instead of on its surface. Invariably, this in-ground storage is located no more than a few metres below the surface. Generally, these storage facilities are well engineered, with elaborate methods of detecting and preventing any leakage of contaminants from the packages.

In this paper, storage means holding the waste material in engineered facilities on the surface of the ground or within a few tens of metres of the surface. Storage is inherently temporary, with the implication that the waste material will be transferred at some future time to a permanent repository, i.e. a disposal facility.

2.2. DISPOSAL FACILITIES

Among technical experts, the generally accepted method for disposing of radioactive waste is to contain the waste and isolate it from the environment generally accessible to humans. Isolation of the types of waste discussed in this report is considered to be best achieved through its emplacement at significant depths underground, that is, by ‘geological disposal’. Containment and isolation of the waste is provided both by the containers into which the waste is put before being emplaced in the repository and by various additional engineered barriers and the natural barrier provided by the host rock. The essence of disposal is that protection of present and future generations and the environment is provided by a passive system made up of engineered and natural barriers.

Geological disposal can be undertaken in a number of geological formations, the most commonly studied rock types being clay, salt, and hard magmatic, metamorphic or volcanic rocks such as granite, gneiss, basalt or tuff. The depth at which the disposed material would be emplaced depends to a large extent on the type of formation used and the isolation capacity of the overlying formations. Suitable clay formations, for example, tend to occur in layers of a few hundred metres thickness at a depth of a few hundred metres. Salt deposits occur as bedded slat layers or salt domes at this or greater depths. For disposal in hard rocks, the usual design depth is between 500 and 1000 m, and the aim is to use parts of the rock formation that contain very few large fracture zones or faults.

The defining characteristic of disposal, as opposed to storage, is that there is no intention to retrieve the waste material, and there is minimal reliance on long term active controls. In other words, the emplacement of the waste is intended to be permanent. Ultimately, a disposal facility will be closed and sealed, and from the surface there might or might not be any indication of the existence of the facility that is at some considerable depth below. In most rock types, a repository can be designed so that closure of the facility can be delayed for a period of several tens to a few hundred years. In this period, the repository and the surrounding environment can be monitored if desired, and the facility can be designed to allow for retrieval of the emplaced material if required.

3. FACTORS RELEVANT TO THE SAFETY AND SUSTAINABILITY OF STORAGE FACILITIES

Following the 1992 United Nations Conference on Environment and Development in Rio de Janeiro, sustainability has become one of the guiding ideals for environmental policy making. Sustainability is achieved by: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” [11]. Regardless of the type of development, the challenge is always to balance competing environmental, social and economic dimensions, ‘the three pillars’, in a sustainable manner. The IAEA was mandated to examine the sustainability of long term storage, and especially the implications for safety compared with those of disposal [10]. Hence, in the discussion that follows, sustainability and safety aspects of long term storage will be compared with those of geological disposal.

Storage is an important element in the safe management of radioactive waste and may be required for different purposes at different stages in the management of waste. It is necessary to store spent fuel and some other types of waste for a period of time to allow radioactive decay to reduce the levels of radiation and heat generation. For other types of waste it is an interim step in the overall process of waste management and lasts for comparatively short periods of time.

The concern expressed by a number of parties that have considered longer term storage of waste arises when the period of storage becomes very long, more than several tens of years. Their concern increases further if it becomes apparent that the storage phase might become, de facto, perpetual. Parties that express this point of view are generally concerned that delaying the decision to dispose without a definite plan for the future timing of disposal leads to an open-ended managerial and financial commitment. Opinions vary, however, because some concerned groups in society have expressed a strong preference for continued surface storage of radioactive waste with ongoing surveillance. Some of the arguments put forward in support of the two different opinions are summarized in the following sections.

3.1. SAFETY

Storage of radioactive waste has been demonstrated to be safe over some decades and can be relied upon to provide safety as long as active surveillance and maintenance is ensured. In contrast, geological disposal promises long term safety without surveillance and maintenance.

The feasibility of safely storing radioactive waste over periods of decades has been clearly demonstrated during the operation of existing facilities. The deficiencies of some of the older storage practices have been recognized and corrected in modern facilities. In fact, the possibility of correcting any problems which might occur can be seen as an advantage of surface storage.

When waste packages are stored it is inevitable that some structural degradation of the packages and their contents will occur over time. This deterioration will require that the waste be transferred at some time in the future, if not to a disposal facility then to another storage facility. The longer the waste is stored before transfer to another facility, the greater are the probabilities that such degradation will occur, with a resultant potential of radiation exposure for the workers who will eventually have to carry out the transfer and handling operations. In this regard, long term safety is not well served by very long periods of storage. Furthermore, waste stores are vulnerable to inadvertent or deliberate intrusion by humans if not kept under close surveillance. This places obligations on future generations to maintain active surveillance of waste stores.

Geological disposal promises to provide containment and isolation of radioactive waste from the human environment for the very long periods required. As discussed earlier, geological repositories are designed to provide this isolation without the need for active controls, i.e. they are passively safe. Safety concerns due to possible human intrusion into the waste are very much reduced as compared to surface storage, owing mainly to the significant depths under the surface at which geological repositories will be located. However, while most experts are convinced that geological disposal provides the best solution for the management of high level waste, experience of operating repositories has not yet been obtained.

3.2. MAINTENANCE/INSTITUTIONAL CONTROL

Maintenance is easier on the surface than underground, but institutional controls cannot be maintained for the period that the wastes remain hazardous.

All human made facilities require maintenance to preserve their integrity. It follows that if the integrity of a structure is essential to protecting the health and safety of people and the environment, ongoing maintenance will be required to avoid gradual deterioration of the protection afforded by the facility. Ongoing maintenance requires the continued existence of authorities and institutions that can ensure that essential maintenance is carried out. Sometimes the period of time during which such institutions are relied upon is referred to as the institutional control period.

Maintenance requires both the detection of deficiencies and their repair. Not only is it easier to repair anything that needs to be repaired when it is on the surface and accessible, compared with when it is underground, but it is also easier to detect deficiencies at their formative stage in a facility that is located on the surface. Effective maintenance, therefore, is favoured by a surface location. On the other hand, geological disposal systems are designed so that any failure in a protective barrier should not have an impact on people and the environment because of the presence of other independent engineered and natural barriers. Maintenance should not therefore be required.

Since adequate protection of humans and the environment will continue only as long as maintenance is continued on storage facilities, and since some of the radioactive material in storage will remain hazardous for many thousands of years, maintenance — or institutional control — would be required for such periods of time or until permanent disposal is implemented. A review of world history reveals that turmoil and change usually occur in much shorter periods of time and therefore that it is unlikely that any societal infrastructure currently in place or envisaged would last for the time period needed.

3.3. RETRIEVAL

Retrieval of material is easier from surface facilities than from underground facilities, but geological disposal can be developed in stages so that the possibility of retrieval is retained for a long time.

An advantage of surface storage is the ease of retrieving material if it should be decided to do so. Having the possibility of retrieving the waste preserves the option for future generations to make different decisions concerning the existing radioactive waste inventory. For example, it gives future generations the option of recycling the material by reprocessing.

Recent work has shown, however, that it is feasible to develop a disposal facility in a gradual, step-by-step manner, retaining the ability to reverse actions and decisions taken in previous steps if necessary. This avoids decisions having to be made earlier than necessary or some decisions having to be changed at a later date, thereby allowing future generations more flexibility than earlier disposal concepts would have provided. For example, the decision to close the facility can be delayed. Also, the facility can be designed and operated to facilitate later retrieval of the emplaced waste if so desired. An important development in this connection is that monitoring methods now exist that can be used for prolonged periods of time without breaching the integrity of the facility.

Provisions for retrievability can be incorporated into both storage and geological disposal facilities. However, retrievability remains an option only as long as institutional controls and the necessary technical expertise exist and where a suitable alternative management option for the waste has been developed. If all these elements exist, retrievability would be possible for both storage and disposal.

3.4. SECURITY

Putting hazardous materials underground increases the security of the materials.

Over the last few decades, the security of nuclear materials has been of increasing concern. Occurrences of illicit trafficking and the events of 11 September 2001 in the USA have heightened these concerns. The security threat is one of either unauthorized possession, theft of the material for illicit use later, or sabotage to cause incidents on the site, e.g. by dispersing the material to the environment.

While nuclear material has traditionally attracted security precautions to prevent it falling into unauthorized possession, it is now recognized that non-fissile material must also be protected because of the possible threat of deliberate spreading of contamination by terrorists. The material is obviously much more vulnerable to attack if placed on the surface. In geological disposal facilities, it is beyond the reach of all but the most determined and sophisticated of individuals or groups.

Many current storage facilities are located on the same site as other active nuclear facilities, and therefore benefit from the overall site security arrangements. If the surface storage continues longer than the operational lifetimes of the other active facilities on-site the security measures will have to be continued independently.

3.5. COSTS

Disposal has a large capital cost; storage has a significant operating cost.

In the context of storage and disposal, sustainability would require that the costs for ongoing and long term management of storage and disposal facilities be internalized; internalized costs are costs that are borne directly by those who receive the benefits. The United Nations Commission on Sustainable Development has called upon governments to internalize radioactive waste management costs to the maximum extent possible [12]. If long term storage is to be sustainable, sufficient funds should be set aside to maintain ongoing storage and address future management actions such as refurbishments, reprocessing or disposals. Estimates for long term financing are based upon discounted costing methods that are very sensitive to future inflation and interest rates, not to mention institutional stability. Long term interest and inflation rates cannot be predicted with accuracy; cost projections for actions beyond one generation (about 30 years) would have a great deal of associated uncertainty. Hence, any estimate for the funding required to sustain long term storage will have large uncertainties. Although ongoing storage requires the continuing expenditure of resources to ensure safety and security, the annual resource requirement is much less than is needed during the limited period for developing, constructing and operating an underground disposal facility.

The very large capital cost associated with a disposal facility is a significant factor, especially given the long time (of the order of 20 years and more) between the start of work towards a geological disposal option and the emplacement of waste in the facility. Many jurisdictions have taken the step of requiring utilities that generate nuclear power to set aside funds on a continuing basis to pay for the future cost of disposal of the related waste (i.e. costs are internalized).

3.6. COMMUNITY ATTITUDES

Storage facilities tend to excite less public opposition than disposal facilities.

For several reasons, there may appear to be less opposition to siting or expanding a storage facility compared with a disposal facility. It is well established that the level of acceptance of new or expanded storage facilities is greater in communities that have lived alongside nuclear installations for many years — often because it is just a continuation of existing practice. Establishing a disposal facility is a process with many decision points, any one of which can lead to rejection — there are generally fewer decision points in the process of expanding existing storage facilities. Storage is understood to be an intermediate step in the management of wastes and disposal is permanent — perhaps another reason why storage appears to enjoy greater acceptance.

Familiarity with the management of nuclear materials, confidence in safety and employment opportunities can foster community acceptance of storage facilities in communities where nuclear installations already operate. However, this does not mean that concern is not voiced when a proposal is made to expand an existing facility or build a new facility. Acceptance is mostly conditional upon the storage facility being a temporary installation, not the final destination for the wastes; the option of perpetual storage seems to receive little acceptance.

Community acceptance for siting a geological disposal facility is linked to a number of issues. Concerns are often expressed about the safety of such facilities and the ability to detect and mitigate any problems that may occur. The permanence of disposal is unattractive to some because it deprives future generations of the option to choose how the wastes are managed. Transport of waste is also sometimes cited as an issue where community acceptance is low, in spite of an impressive record of transport safety worldwide. In contrast to this, new storage capacity may simply entail extension of an existing licence at a site where nuclear installations are already operating. This perhaps contributes to a perception that storage facilities are more accepted than disposal facilities.

3.7. TRANSFER OF INFORMATION

Long term storage of radioactive waste requires transfer of information to future generations.

The operations needed to ensure the safety of long term waste storage, such as security, regulatory oversight and inspections, require that a great deal of information be retained. Since maintenance operations on the facility must be expected, as well as eventual transfer of the waste packages, the information required relates to the waste inventory, its characteristics and storage location, the technology used for conditioning and packaging, and the design of the storage facility. All this information must be retained for the entire life of the storage facility.

Not only must this information be retained, it must also be readable and understandable to future generations. That presents a potentially significant difficulty. Traditional paper based systems are susceptible to physical degradation with time through various mechanisms such as gradual disintegration because of poor quality paper or ink, decay of organic material, fire, flood, fungal attack, insect or rodent damage, etc. Modern technologically based systems (e.g. computerized data storage) are more resistant to many of these factors, but have their own specific vulnerabilities. For example, they require constant updating and maintenance to ensure that the storage media have not become obsolete due to changes in technology, and software can quickly become unreadable with the development of new systems. There is also the possibility that even with intact records future generations might not have the knowledge that is required to understand them.

Ideally, the same information for a waste disposal facility as for a storage facility would be available to future generations. But if the information transfer into the future is incomplete, the consequences in the case of a disposal facility should be of no safety concern given that its design and construction are intended to place little or no reliance on human activity for long term safety. Therefore, from the perspective of information transfer, safety in the long term is better ensured by disposing of the waste material as soon as practicable.

For nuclear materials, safeguards have to be kept in place to maintain the continuity of knowledge that nuclear material has not been diverted. Nations that are signatories of the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) [13] are required to ensure that nuclear materials within their borders are not diverted for undeclared or non-peaceful uses. The IAEA, through its safeguards role, is responsible for providing independent, international verification that governments are abiding by their commitments with respect to the NPT. The system of safeguards is well established for surface storage facilities.

During the operational phase, safeguards for geological disposal facilities will require additional measures and effort compared with surface storage. Safeguards of nuclear material in geological disposal will have to continue even after facilities have been closed and sealed. However, it is expected that in the post-closure phase of geological repositories safeguards assurances will be obtainable with a very limited effort.

4. DISCUSSION

It is clear that the issue of whether to pursue long term storage or dispose of radioactive waste is not one that is solely technical. Other factors of a social, political, economic, and ethical nature are also very relevant. It is equally clear that these factors do not all influence the debate in the same direction. For example, current societal opinion, although not uniform, does not appear to be strongly in favour of disposal. This results in de facto continued storage on the surface, since it is an exception to find a community that supports the development of a disposal facility in its midst. Political considerations put a great deal of weight on societal opinions since those affect the way the electorate votes. Although there are good reasons to favour disposal, they do not provide a strong political driving force towards disposal.

Economic considerations are complex and variable depending, for example, on whether a fund has been created specifically to pay for disposal and is protected against use for other purposes. Internalized environmental costs are a key indicator for the long term sustainability of a practice. If a fund exists to internalize disposal costs, there is an economic argument for proceeding with disposal, but if it does not exist the capital cost of a disposal facility can result in economic considerations favouring the continuation of storage. Given that discounted costs have large uncertainties over periods exceeding one generation, and given the inherent uncertainties regarding future disposition of the wastes, it is not clear how the costs for long term storage should be internalized.

It is not desirable to leave an unsolved problem to a future generation, although it is also not desirable to deprive future generations of certain options because of actions taken by the present generation. Some ethicists, however, claim that this argument would quickly lead to justifying no action being taken by the current generation on many issues, and that pre-emption of future options is acceptable ethically provided that the current action is well motivated and reasonable in the light of current knowledge.

Long term surface storage is not the best option from the security point of view because spent nuclear fuel and high level wastes in surface storage are more vulnerable to theft and sabotage. Security considerations, which carry increasing weight, lead strongly and unequivocally to disposal being desirable at as early a date as is reasonable. Placing the waste material underground, even without finally closing the facility, greatly increases the difficulty of access to the material by unauthorized persons.

With respect to safety, there are two conflicting arguments. The fact that safe surface storage requires ongoing inspection and maintenance is a strong argument for underground disposal since at some point in the future discontinuance of the present infrastructures that provide for such inspection and maintenance must be expected. The main contradictory argument is the claim that the ease of corrective action in surface facilities can contribute to an improved level of safety ensurance. International experience shows that the need for such corrective actions can be reduced relatively easily given due diligence by the designers and operators of the facility and the national regulators. A facility can be designed to take advantage of easy access to some extent for adequate performance; but a facility can also be designed not to need corrective actions when it is known in advance that access will be difficult. And of course it must be remembered that access to an underground facility, while more difficult than to a surface one, is still possible. Whatever the short term situation, the safety of surface storage facilities will degenerate in the long term if active controls are not maintained.

The argument that action should be postponed until a scientifically better solution is developed is not convincing. After several decades of research on the disposal of nuclear wastes, geological disposal is the only approach that has gained widespread credibility in the scientific community and therefore it is highly unlikely that some completely new idea will be forthcoming. A further consideration is that if geological disposal provides a good level of safety it is not necessary, or even responsible financial management, to expend further resources on the development of alternatives.

5. CONCLUSIONS

Storage is a necessary phase in safely managing most types of radioactive waste. During the storage phase, for example, the radiation levels and heat generation intensities may decrease to more manageable levels. Also, storage is a necessary part of waste treatment and conditioning programmes. Storage has been carried out safely within the past few decades, and there is a high degree of confidence that it can be continued safely for limited periods of time.

The safety of long term storage requires the maintenance of the industrial, regulatory and security infrastructure as described in previous sections. Long term safety also requires that future societies will be in a position to exercise active control over these materials and maintain effective transfer of responsibility, knowledge and information from generation to generation. Long term storage is only sustainable if future societies can maintain these responsibilities.

Active controls cannot be guaranteed in perpetuity because there is no guarantee that the necessary societal infrastructure can be maintained in perpetuity. Therefore, for the types of radioactive wastes considered here — wastes that remain hazardous for thousands of years — perpetual storage is not considered to be either feasible or acceptable.

The safety of geological disposal is widely accepted amongst the technical community and a number of countries have now decided to move forward with this option. Storage and disposal are complementary rather than competing activities and both are needed. However, the timing and duration of the process of moving from storage to disposal is influenced by many factors, not only the sustainability of long term storage. Strategies for storage and disposal need careful consideration in light of the many issues involved. These include transport of radioactive wastes from storage sites to disposal sites, security of the waste, retrievability of the waste from storage, safe packaging and conditioning of waste for long term storage and disposal, availability of suitable disposal sites, confidence that adequate levels of safety can be achieved, and the availability of finances.

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